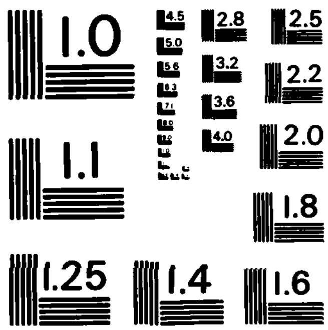
AD-A162 248 PHOTOVOLTAIC POWER SYSTEM PERFORMANCE: A CASE STUDY AT FORT HUACHUCA ARIZ..(U) CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL D M JONCICH ET AL. OCT 85 CERL-TR-E-86/01 MIPR-A1049 — 1/1

UNCLASSIFIED — F/G 10/2 — NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

US Army Corps of Engineers
Construction Engineering Research Laboratory

USA-CERL

TECHNICAL REPORT E-86/01
October 1985

AD-A162 248

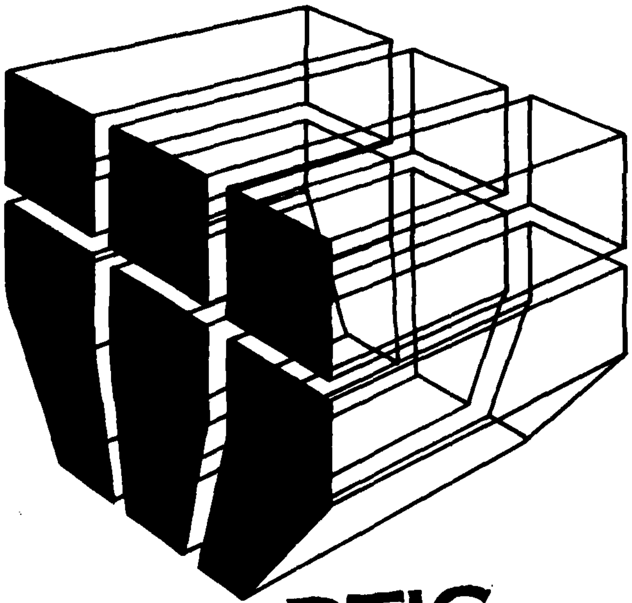
Photovoltaic Power System Performance: A Case Study at Fort Huachuca, Arizona

by
D. M. Joncich
R. A. Ducey

A 5-kW-peak, grid-connected, photovoltaic (PV) power system is described. In this case study, the PV system in service at the Holman Guest House, Fort Huachuca, AZ, is evaluated for baseline data that will allow comparisons to be made with other PV systems. Designed and installed at a cost of $112,000, the system was funded by the Department of Energy's Federal Photovoltaic Utilization Program.

Performance data gathered during 1983 by Arizona State University are summarized. The Holman Guest House power system provided nearly 8600 kWh of electricity during the test period, with no system failure and only minimal maintenance. This corresponds to approximately 11 percent of the facility's electrical requirement.

If the system operates reliably for 20 years, the cost of photovoltaic energy would be roughly $0.50/kWh. Based on information gained from the demonstration project, the feasibility of future photovoltaic systems is discussed.



Approved for public release; distribution unlimited.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: CERL TR-E-86/01	2. GOVT ACCESSION NO.: AD-A162 248
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): PHOTOVOLTAIC POWER SYSTEM PERFORMANCE: A CASE STUDY AT FORT HUACHUCA, ARIZONA	5. TYPE OF REPORT & PERIOD COVERED: FINAL
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): D. M. Joncich, R. A. Ducey	8. CONTRACT OR GRANT NUMBER(s): MIPR A1049 (1981)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Construction Engr Research Laboratory, P.O. Box 4005, Champaign, IL 61820-1305	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: October 1985
	13. NUMBER OF PAGES: 21
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service
Springfield, VA 22161

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fort Huachuca, AZ
Photovoltaic power systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A 5-kW-peak, grid-connected, photovoltaic (PV) power system is described. In this case study, the PV system in service at the Holman Guest House, Fort Huachuca, AZ, is evaluated for baseline data that will allow comparisons to be made with other PV systems. Designed and installed at a cost of $112,000, the system was funded by the Department of Energy's Federal Photovoltaic Utilization Program.

(Cont'd)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

BLOCK 20 (Continued)

Performance data gathered during 1983 by Arizona State University are summarized. The Holman Guest House power system provided nearly 8600 kWh of electricity during the test period, with no system failure and only minimal maintenance. This corresponds to approximately 11 percent of the facility's electrical requirement.

If the system operates reliably for 20 years, the cost of photovoltaic energy would be roughly $0.50/kWh. Based on information gained from the demonstration project, the feasibility of future photovoltaic systems is discussed.

FOREWORD

This work was performed by the Energy Systems Division (ES) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL) under Military Interdepartmental Procurement Request A1049 (1981). USA-CERL did the work for the U.S. Department of Energy through the U.S. Army Fort Belvoir Research and Development Center (BRDC). S. Cerami, DRDME-EAC, was the BRDC Technical Monitor. The work was coordinated with the office of the Chief of Engineers (OCE) with Technical Monitors E. Zulkofske, DAEN-ECE-E, and B. Wasserman, DAEN-ZCF-U.

Appreciation is expressed to Dr. P. Russell and K. Tygret of Arizona State University for developing the system monitoring plan and to K. Van Karsen, D. Oliver, and W. D. Clark from the Fort Huachuca Directorate of Engineering and Housing for their work in gathering the performance data. Support for the project was also provided by Drs. A. Averbuch and D. Johnson of USA-CERL. R. G. Donaghy is Chief of USA-CERL-ES.

COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

PHOTOVOLTAIC POWER SYSTEM PERFORMANCE: A CASE STUDY AT FORT HUACHUCA, ARIZONA

1 INTRODUCTION

Background

The U.S. Department of Energy (DOE) Act of 1978[1] mandated that the DOE cooperate with other Federal agencies to implement a program accelerating the procurement and installation of photovoltaic (PV) systems at Federal facilities. Public Law 95-619[2] authorized the Federal Photovoltaic Utilization Program (FPUP) to provide for the acquisition of PV solar electric systems at an annual level great enough to encourage development of low-cost production techniques. Other objectives of this program were to:

1. Accelerate the growth of a commercially active and competitive industry that would make PV systems available to the general public.

2. Reduce fossil fuel consumption and costs for the Federal government.

3. Stimulate the general use, within the Federal government, of methods for minimizing PV life-cycle costs.

4. Develop performance data on PV technology.

To achieve these objectives, FPUP supported PV applications with significant market potential in the private sector, in foreign countries, and within Federal organizations. FPUP was implemented in four funding cycles and included demonstrations ranging from small, remote systems to larger, grid-connected ones. The project described in this report was funded as part of Cycle III. It provided the Army, through the Fort Belvoir Research and Development Center, its first opportunity to apply a PV power system to a permanent facility.

Purpose

The main purpose of this work is to analyze the performance of a 5-kW-peak grid-connected PV power system designed by Monegon Ltd. under contract to the U.S. Army Construction Engineering Research Laboratory (USA-CERL)[3] and to evaluate the performance data for potential use as a basis in analyzing future PV systems–both remote and grid-connected. A secondary objective is to gain an understanding of the PV system's operation and maintenance (O&M) requirements to help installations using the system receive optimal energy savings.

Approach

A contract was awarded to Arizona State University (ASU), in January 1983 to monitor performance of the PV system installed at the Holman Guest House, Fort Huachuca, AZ. Data gathered by ASU were then analyzed. The ASU team also was to provide assistance with system O&M to gain experience that would allow them to recommend O&M procedures tailored to the system.

2 SITE AND SYSTEM DESCRIPTION

Site

The Holman Guest House is a one story, motel-like structure with a nominal roof area of 12,000 sq ft* available for mounting the PV array (Figure 1). The roof contains a ridge that runs east-west along its long dimension; the pitch along the other axis is 0.5 in./ft. The building is serviced by 100-amp 120/208 three-phase electrical mains and is metered separately. Recording ammeter readings taken onsite indicated that the facility's baseline electrical consumption was about 9 kW at the time of PV system installation.

The Guest House was selected for the project because it is located in a well lit, high visibility area and has a properly oriented, nearly flat roof. In addition, Fort Huachuca's sunny climate was expected to allow maximum electrical output from the PV array.

---

[1] Public Law 95-238, *Department of Energy Act*, 92 Stat. 47 (25 February 1978).

[2] Public Law 95-619, *National Energy Conservation Policy Act*, 92 Stat. 3206 (9 November 1978).

[3] D. M. Joncich, *A Photovoltaic Power System for the Holman Guest House, Fort Huachuca, AZ*, Technical Report E-195/ADA 142646 (USA-CERL, May 1984).

*Metric conversions: 1 sq ft = 0.0929 m^2; 1 in. = 2.54 cm; 1 kWh = 3.6 MJ; 1 W = 1 J/sec.

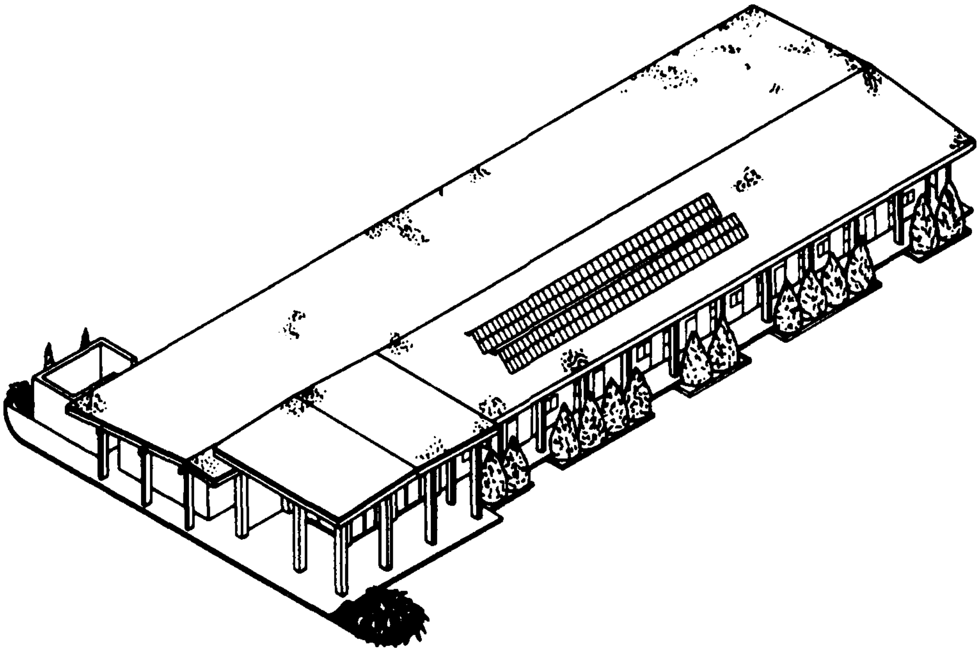


Figure 1. The Holman Guest House, Fort Huachuca, AZ (with roof-mounted PV array).

System

Installation of the PV system was completed in October 1982. The system contains a PV array mounted on the roof in an aluminum framework secured at a fixed angle of 30 degrees from the horizontal. The array direct current (d.c.) output (about 210 V) is converted to alternating current (a.c.) by an inverter located inside a protected area next to the building. The inverter output powers part of the house's electrical loads.

The array consists of 196 Solarex Corporation Model 5300 EG panels. Under full sunlight, each panel produces about 31.5 W at 15 V d.c. The array is wired so that 14 parallel strings of 14 panels are connected in series. Each string is provided with a blocking diode to minimize degradation of the array performance should one of the strings fail. Each panel also has a bypass diode that allows a single string to operate, even if a panel in that string fails (Figure 2).

The panels are constructed from a sheet of tempered glass to which solar cells are bonded. The cells are wafers cut from 4-in.-diameter single crystals of silicon. Each panel has 38 cells connected in series. The base material is p-type, boron-doped silicon. The cells have electrical contacts silk-screened on the front and are encapsulated in ultraviolet-stabilized silicon rubber. The glass-cell assembly is enclosed in an aluminum frame.

The PV system feeds power into the utility grid if electricity production exceeds the demand at the Guest House (see Figure 3). Similarly, the grid provides power during periods of excess demand and at night. System operation is totally automatic.

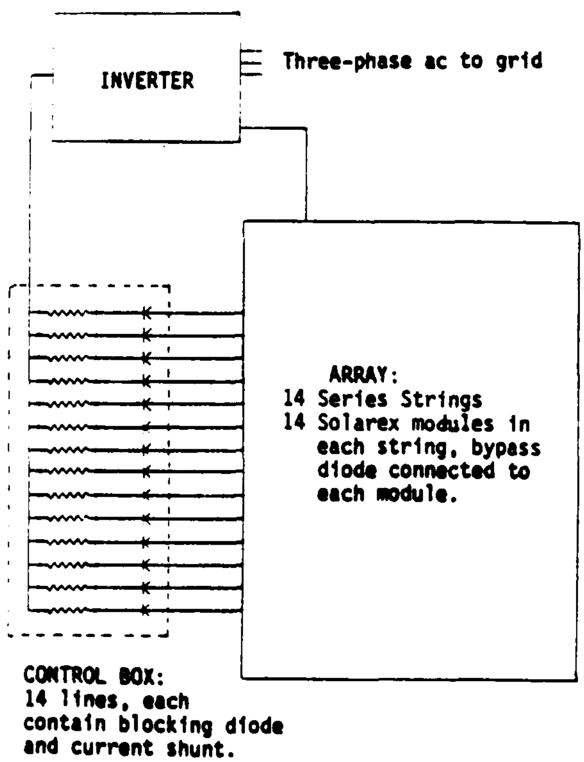


Figure 2. PV system overview.

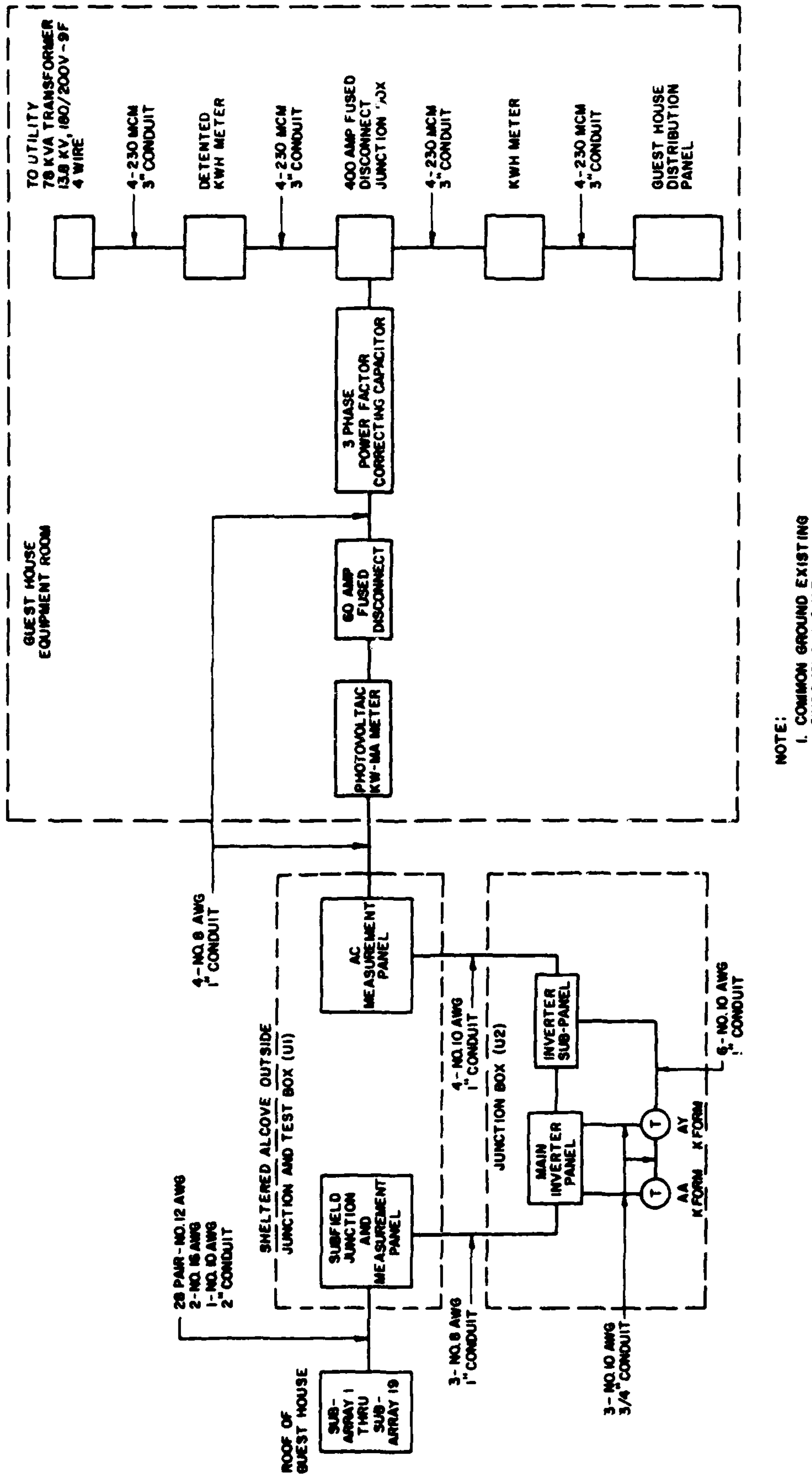


Figure 3. System schematic.

The system inverter converts power produced by the PV array into 208-V, three-phase a.c. The inverter is a solid-state, line-commutated device designed specifically for this application. Using the a.c. utility lines to determine the voltage waveform and frequency, the inverter produces high-quality, 12-pulse output at an efficiency of about 85 percent. It disconnects and shuts down automatically when the grid power is interrupted.

The site instrumentation consists of three totalizing a.c. kWh meters. The first records the total PV system power output. The second measures the total power provided by the utility grid to the Guest House; it has been detinted so that it will not decrement when energy from the PV system is fed back into the grid. The third meter records the Guest House's total power consumption. A terminal strip also has been installed at ground level to facilitate measurement of the PV system's d.c. and a.c. voltages and currents.

A surge arrester protects the electronic circuitry from lightning. This device uses a silicon-oxide junction which is normally insulating, but which ionizes in the presence of a high voltage. When ionized, this junction protects the components downstream. Lightning rods were not considered necessary because nearby buildings and lamp posts are higher than the Guest House.

Appendix A summarizes the equipment contained in the PV system at the Guest House.

3 SYSTEM PERFORMANCE

Acceptance Testing

The PV system at Fort Huachuca was acceptance-tested in two phases. In the first phase, the contractor installing the system submitted all relevant project documentation; in the second phase, Fort Huachuca Directorate of Engineering and Housing (DEH) staff inspected the site to substantiate that the system, as installed, met the project specifications. System operators also were trained at this time.

During the second phase, DEH developed a list of construction deficiencies and recommended they be corrected before the system was accepted. Most of these items were minor and were addressed by the contractor, Monegon Ltd., in December 1982. The Government formally accepted the PV system at the Guest House in February 1983, but the system had been functionally operational since October 1982.

Data Collection and Analysis

In January 1983, ASU was contracted to monitor the PV system and gather data that would document its first year's performance. ASU was also to assist DEH staff with O&M.

A list of definitions was developed for consistency in reviewing data in the ASU report. Table 1 summarizes these definitions.

The monitoring contract specified which system parameters were to be recorded and tabulated. Those specifications and results drawn from the ASU report can be summarized as follows.

Monthly Values for Solar Energy Available to the PV Array

From April to October 1983, a faulty integrating system was collecting data for array output and solar insolation. A new system was subsequently installed; data from the new system are in Table 2. This table shows solar insolation levels higher than predicted for that time of year. Data on array output (Table 3) confirm that more energy was produced (and, therefore, more was available) in the latter part of 1983 than expected. Table 3 also shows, however, that data from the last quarter of 1983 is atypical for most of the year. Based on this observation, it is safe to say that solar insolation, during 1983, fell below the predicted mean.

Monthly Electrical Energy Delivered by the PV System and Utility Grid

A logsheet was developed and ASU used it to record data and calculate energy delivered to Holman House. Appendix B contains sample logsheets. Voltage and current readings for each PV array were taken to insure that the system was completely operational. The three power meters kept records of the total power consumed by the Guest House, power delivered by the PV system, and power delivered by the utility grid. Table 3 includes the data on power delivered by the PV array compared with predicted values. Approximately 11 percent of the facility's 80,690-kWh annual energy requirement was provided by the PV system.

Table 3 shows wide variance between the values predicted and actual data recorded. This is partly due to downtime caused by the utility grid. Also, Monegon had provided predicted values which were rough estimates for a "typical" year. It was observed that energy available to the array fell below the mean during 1983.

Table 1

Explanation of Terms

Term	Unit of Measure	Definition
Capacity Factor	%	Ratio of amount of energy actually produced to amount that would have been produced at the system's rated output, 24 hr/day.
Solar insolation	kWh	Direct solar energy to the array.*
Inverter input/array output	kWh	Amount of energy array produces from sunlight.**
Array efficiency	%	Ratio of array output to solar insolation, × 100.
Inverter efficiency	%	Ratio of PV output (kWh) meter readings to inverter input, × 100.
System efficiency	%	Product of array efficiency ratio and inverter efficiency ratio, × 100.
Downtime	Hr	Period of time the system was not in operation.

*The array area is 1051 sq ft or 97.64 m^2. A conversion factor of 3.9056 must be used to convert mV readings from the meter to kWh.

**The amount of d.c. current multiplied by 0.336 is the energy produced in kWh.

Table 2

Energy Available

	Solar Insolation (kWh)		
Dates	Actual	Predicted	Actual/Predicted (%)
10–29 Nov 83	10598	7440	142
30 Nov–6 Dec 83	2940	2146	137
7–30 Dec 83	12116	7358	165
31 Dec 83–10 Jan 84	3853	3716	104
11–18 Jan 84	4584	3041	151
19 Jan–3 Feb 84	9569	5713	167

Table 3

Energy Delivered by the PV Array

Month (1983)	Actual (kWh)	Predicted (kWh)	Actual/Predicted (%)
January	563	572	98
Feburary	674	669	101
March	858	955	90
April	858	1150	75
May	763	1316	58
June	688	1274	54
July	749	1117	67
August	544	1049	52
September	714	928	77
October	737	796	93
November	750	598	125
December	675	517	131
Annual	8573	10941	78

Table 4

System Downtime*

Date	Duration (hr)	Explanation
3 Feb 83	111	Utility line faults and resulting power bumps and repairs
20 Apr 83	72	Post power outage
8 Jun 83	24	Three separate outages, 8 hr each
13 Jun 83	8	Power outage
11 Jul 83	48	Power outage
1 Aug 83	48	Thunderstorm caused outage
19 Aug 83	96	Power outages

*System downtime was considered to be time during the previous week when the system was unable to operate.

The logsheet was also used to record any downtime and its cause. Weather conditions, including temperature, solar insolation level, and a general description were specifically recorded or given in a "notes" section. This information helps clarify the system's performance analysis. For example, Table 3 shows that energy production levels in August were only 52 percent of predicted values. But inspection of the logsheets for that period reveals low solar insolation levels due to overcast weather and 144 hr of downtime caused by utility grid outages onpost.

System Downtime

The system downtime recorded on the logsheets is summarized in Table 4; these data include the frequency and duration of grid outages during the data collection period. The table indicates that all downtime was attributable to power outages onpost. The PV array proved quite reliable and never failed to convert energy when conditions external to the system were favorable.

PV System O&M Requirements in Terms of Time and Repair Costs

Other than a problem with some of the test instrumentation, the ASU team was never required to make repairs. Therefore, they had no opportunity to experience hands-on maintenance procedures for the power system. It should be noted that PV systems are advertised as being virtually maintenance-free, needing only periodic checks to ensure they are operating efficiently.

PV System's Average Monthly and Yearly Efficiency

The faulty integrating meter prevented obtaining complete data for this performance parameter, but Table 5 is an accurate indicator of average efficiency for the entire test period. Figure 4 plots the energy curves for a typical "sunny day" and shows that a PV system should consistently convert about 5 percent of the solar energy incident on the array. The Holman Guest House system efficiency agrees with this predicted value.

PV System's Monthly and Yearly Capacity Factors

The capacity factor for any power system is based on the amount of energy the system can produce in 24 hrs if run at its peak. Conditions for earthbound PV systems allow only a fraction of this energy production level and capacity factors are generally lower than those of other power plants.

Fort Huachuca's PV is rated at 5 kW peak. The monthly base level, then, is 120 kWh/24 hr, times the number of days in the month. Table 6 shows a consistent factor of 20 percent, which is typical for PV systems.

Monthly and Yearly Dollar Savings in Energy Delivered

Dollar savings were calculated by multiplying the PV system output by the local electrical rate of $0.0589/kWh. Table 7 indicates an annual savings of

Table 5

System Efficiency*

Date	Solar Insolation (kWh)	Array Output (kWh)	PV System Output (kWh)	Array Eff. (%)	Inverter Eff. (%)	System Eff. (%)
10 Nov 83	19796	1087	922	5.5	84.9	4.7
29 Nov 83	10598	577	492	5.4	85.4	4.6
6 Dec 83	2940	160	133	5.4	84.4	4.5
30 Dec 83	12116	651	550	5.4	84.4	4.6
10 Jan 84	3853	206	168	5.3	81.6	4.3
18 Jan 84	4584	251	215	5.5	85.7	4.7
2 Feb 84	9569	530	453	5.5	85.3	4.7

*System efficiency is based on the system's output and solar insolation available to the array.

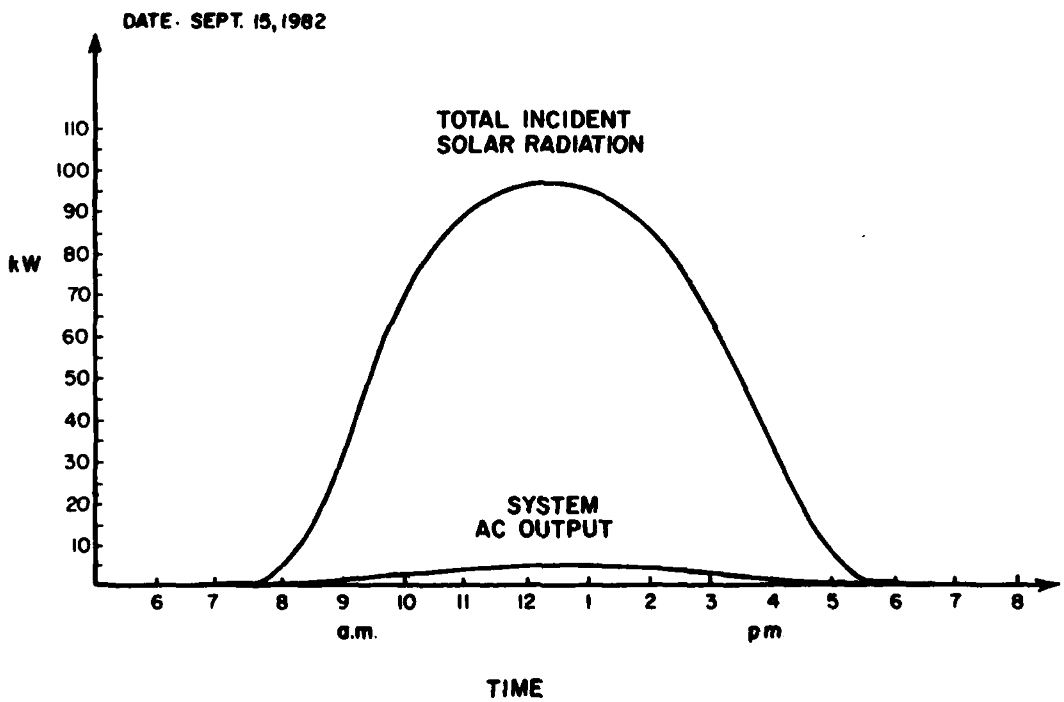


Figure 4. PV system "sunny day" performance.

Table 6

Capacity Factors by Month and Year

Month (1983)	Actual (kWh)	Capacity (kWh)	Capacity Factor (%)
January	563	3720	15
February	674	3360	20
March	858	3720	23
April	858	3600	24
May	763	3720	21
June	688	3600	19
July	749	3720	20
August	544	3720	15
September	714	3600	20
October	737	3720	20
November	750	3600	21
December	675	3720	18
Annual	8573	43800	20

Table 7

Cost Savings

Month (1983)	Output (kWh)	Savings ($)
January	563	33.16
February	674	39.70
March	858	50.54
April	858	50.54
May	763	44.94
June	688	40.52
July	749	44.12
August	544	32.04
September	714	42.05
October	737	43.41
November	750	44.18
December	675	39.76
Annual	8573	504.96

$505. If all conditions remain the same, it would take 222 years for the project to pay back its original $112,000 investment. However, this projection is meaningless since economic conditions will not remain constant.

O&M Assistance

In addition to compiling the test data, ASU was to assist Fort Huachuca's DEH with O&M. The PV system's reliability kept these duties to a minimum and the ASU team made only routine site trips throughout the year. The monitoring contract listed specific areas for which assistance would be provided. Those items, along with ASU's responses to them, are listed below.

System Logsheet to help DEH Collect Required Data

The logsheet ASU developed has already been discussed in this report and a sample copy is in Appendix B. DEH recorded data approximately bi-weekly and sent it to ASU for evaluation.

Recommended Type and Frequency of Routine System Maintenance

Based on ASU's analysis, some procedures can be suggested that should help in PV system maintenance.

First, the southern Arizona desert experiences diverse weather conditions. In the event of lasting snow cover or heavy dustorms, the panels should be cleaned as soon afterward as weather permits. Panels and wires should also be checked at this time for possible damage.

In addition, the Gemini inverter is a heat-sensitive part and should always be open to ventilation. The inverter has several small, integrated circuit boards, fuses, relays, and optoisolators that can develop faults. For troubleshooting the inverter, it should be emphasized that test instruments must be isolated from earth ground for proper readings.

These limited recommendations reflect the fact that ASU encountered no maintenance problems and only had to make routine checks.

Advisory Services to DEH in Diagnosing System Malfunctions

There were no system malfunctions, but ASU did diagnose a faulty integrating system which was part of the testing instrumentation. The meter recorded power data on solar insolation and array output and was the only equipment failure throughout the test period.

Troubleshooting Procedures for DEH Use in Diagnosing System Malfunctions

ASU summarized the manufacturer's repair and maintenance procedures as follows: troubleshooting of the PV system can be divided between the array and the inverter. If the array is not producing the proper power level, each string should be checked via the control board. Once the faulty string is located, the junction box on the back of each panel in the string should be checked to find the faulty modules

or bypass diodes. Module voltage should be in the range of 12 to 18 V, depending on sunlight and load current. Possible problems result from broken or dirty modules, shorted diodes, or faulty control box wiring. Care must be taken when checking module voltages, since the string voltage can be as high as 250 V and may be lethal.

Troubleshooting procedures for the inverter also involve working with potentially lethal voltages and currents. Always wait 2 min after deenergizing the power source and the utility a.c. power before contacting the inverter wiring. Test instruments must be isolated from each ground when they are used for monitoring the Gemini inverter. Inverter troubleshooting procedures can be broken down into four basic subsystems:

1. Magnetic control. Consists of the d.c. contactor and the front panel control switch. The magnetic control's basic function is to connect the power source to the Gemini inverter. In the event of utility a.c. power outage, the connector will drop out automatically, regardless of switch position, disconnecting the power source from the utility a.c. lines.

2. Power electronics. Consists of the silicon-controlled rectifier bridge assembly (SCR) with associated heat sinks, the firing circuit board, the d.c./a.c. filter networks, and the d.c./a.c. fuses.

3. Control electronics. Contained in the regulator printed circuit board mounted on the inside of the front door.

4. Metering circuit. Consists of the panel meters, current-sensing shunt, and selector switch test circuitry on the regulator board.

When an inverter malfunction occurs, the problem should be isolated to one of these subsystems. Possible problems are blown fuses, a faulty relay or integrated circuit, or a switch malfunction. If parts replacements do not cure the problem, the manufacturer (Windworks in this case) should be contacted for assistance.

Recommended Number of PV System Spare Parts Onhand

Based on its limited experience with O&M, ASU could only estimate what spare parts might be needed in the future. Therefore, the list given to DEH was based on suggestions from the manufacturers and research into other PV projects.

Summary of Any Recurring Problems in System O&M

This contract stipulation proved to be unnecessary.

Performance Summary

Operating in parallel and in synchronization with the local a.c. grid, the system was out of operation only in times of low sunlight or when the a.c. grid was inoperative at the installation site. Maintenance operations consisted of manually returning the system to the interconnected mode after utility outages. The modules, inverter, and interconnective hardware required no attention. If the quality of this PV system's a.c. output is considered adequate in matters such as power factor and waveforms, the system is technically adequate overall. It not only gives early indications of high reliability, but is operating in a safe mode, consistent with good utility practice.

4 CONCLUSIONS AND RECOMMENDATIONS FOR PREDICTING SYSTEM FEASIBILITY

The Fort Huachuca Case Study

A PV system for supplying electrical power to the Holman Guest House at Fort Huachuca, AZ, has been designed and installed successfully. The PV system never failed to convert energy when external conditions were favorable; instances of downtime were almost entirely due to postwide power failures. Energy production levels and efficiencies were consistent with predicted values. Little maintenance and no repairs were required during the test period.

The demonstration project at Fort Huachuca served three major objectives. These were to:

1. Provide the Army a first opportunity to apply PV power technology to a permanent facility.

2. Demonstrate the 5-kW system's easy O&M and reliability in supplying nearly 11 percent of the facility's energy needs. (The only piece of equipment replaced during the O&M monitoring was a recording instrument.)

3. Produce performance data that form a basis for analyzing other PV systems used at Army installations.

Economic feasibility of the Fort Huachuca PV system was never in question. Before the project began,

it was conceded that the initial investment would far outweigh the payback in energy savings. If the system were to continue to operate reliably for the next 20 years, the corresponding electrical cost would be roughly \$0.50/kWh–nearly 10 times the current average rate.

However, projected increases in energy costs and rapidly decreasing PV system costs indicate that a system which pays for itself may be a possibility in the future. Information gained through the Fort Huachuca PV project will help in evaluating these future systems, and in this regard, the project has been a success.

Future Military PV Projects

A complete understanding of the economic feasibility of future military PV projects would require a detailed life-cycle economic analysis. This analysis should consider all system capital and O&M costs, the discount rate, the current price of electricity at the site, and an assumed escalation rate for future electrical prices.

These factors are all part of the fundamental economic questions: how much will it cost, and how much will it save? Based on the experience at Fort Huachuca, these questions can be considered quantitatively.

Initial capital costs, for example, are less than half what they were in 1982. Because of recent developments in amorphous-crystal PV cells, it is projected that, by the early 1990s, a system similar to the one at Fort Huachuca will have reduced in cost by a factor of 10. Another consideration of capital costs is whether the system is grid-connected or remote. Balanced against the high cost of having a utility line brought to some remote facility and a projected low-cost PV system, the PV system may be more economical even though it would require the addition of a storage system.

The question of how much a PV system will save depends on the rates being charged by other power producers. Nuclear, fossil fuel, and hydro-electric power plants have all experienced economic difficulties that have caused their energy rates to increase. The higher these rates, the more economically feasible PV systems become.

For the future, assuming a PV system that produces energy at the same rate as the one at Fort Huachuca would cost about \$15,000, it would take less than 15 years for a simple payback. These assumptions are very rough, but do indicate that future PV systems may become competitive with conventional energy sources, even if only in a supplementary capacity.

APPENDIX A: SUMMARY OF SYSTEM HARDWARE

The following summarizes the system components and their rated capacity:

Modules

Manufacturer	Solarex Co. Model #5300
Rated Output*	
Open-circuit voltage in volts (Voc)	22
Short-circuit current in amperes (Isc)	2.2
Maximum power in watts (Pmax)	35.0
Voltage at maximum power in volts (Vmp)	17.5
Current at maximum power in amperes (Imp)	2.0
Module Output Terminations:	
Exposed terminal screws or standoffs	No
Enclosed terminal screws or standoffs	Yes
Connectors used at output terminations	No
Other means of output terminations	No
Junction box on PV panel is UL approved	
Bypass diodes:	
Diodes built into module circuitry	No
Diodes external to module circuitry	Yes
Contained in a junction box	Yes
External to junction box	No
Diode ratings (external diodes only)	
196-6A MR 751	
Motorola, No	
Specs. available	
Intermodule Wirings:	
Wire size	#12
Wire ampacity	20 amperes
Type of cable	THHN
Type of connectors used (if any)	None
Means of wire routing	In Conduit

Module Mounting Technique:
Direct ______ Integral ______ Standoff ______ Rack XX

*Note: The rated outputs are determined at an air mass of 1.5, an irradiance of 100 MW/cm^2 and a cell temperature of 20°C. The only exception is for Voc which is rated at either 0°C or - 20°C.

Module Grounding Technique (where applicable) ________

See below

____

Module Support Grounding Technique (where applicable) ________

Ground fault interrupt senses the lead from array ground and trips if the difference between array and common ground reaches 200 mA.

Module Listing Agency (where applicable) N/A (no listing)

PV Source Circuits (where applicable)

Rated Output*:

Open-circuit voltage in volts (Voc)	308
Short-circuit current in amperes (Isc)	2.2
Maximum power in watts (Pmax)	420 W
Voltage at maximum power in volts (Vmp)	210
Current at maximum power in amperes (Imp)	2.0

Source Circuit Blocking Diode ________ Yes

Physical location of diodes The main box; South-west corner of Holman house

Diode Ratings

14-6AMR751

Motorola. No Specs.

Available

Source Circuit Electrical Features:

Fuses (or other overcurrent devices)	No
Location	
Disconnects	No (but has ground fault interrupter)
Ratings	
Location	
Ground	No
Location	

Wire Configuration:

Describe the series/parallel configuration of the circuit The array is wired so that there are 14 parallel strings of 14 panels in series.

Source Circuit Listing Agency (where applicable) ________ N/A

PV Output Circuit (PCU input circuit)

Rated Output:

Open-circuit voltage in volts (Voc)	308V
Short-circuit current in amperes (Isc)	30.8 A
Maximum power in watts (Pmax)	6.3 kW
Voltage at maximum power in volts (Vmp)	210 V
Current at maximum power in amperes (Imp)	30 A

PV Output Circuit Electrical Features — type S3460,600V

Blocking diodes Yes — Ratings 45A — Location Main Elec. Box

Fuses (or other overcurrent devices) No — Ratings ____

Location ____

Disconnects No — Ratings ____ — Location ____

Ground Yes — Location ____

Alternative grounding method used Floating

Wiring size #8 — Ampacity 40A — Routing method Placed in 1" conduit taken to Main Elec. Box

Open Circuit Listing Agency (where applicable) ____

Power Conditioning Unit(s)

Manufacturer	Windworks
Model No.	S6-25-20
Number of units	(1)
Location(s)	Main Elect. Box, S-W corner of Holman house
Interactive X or Stand-alone	
Temperature range:	
Operating	32°F to 100°F
Nonoperating	
Mounting requirements:	
Dry	Enclosed and ventilated
Wet	N/A
Test point common at ground	No
Power conditioning unit case grounded	Yes
Input voltage	160-250 Vdc
Input current	0-30 Adc
Input ground	No
Output voltage *Line to neutral*	110-130 Vac
Output current, rated	15 amps
Output current maximum available, any condition of load	15 amps
Output frequency	60 Hz
Output phase	3 phase
Hookup diagram provided	Yes (DWG. No. 808102-00-A)

Output connections made to:

Line 1	Line 1	X1
Line 2	Line 2	X2
Neutral	Line 3	X3
Ground	Neutral Ground	Gnd connection

Listing agency (where applicable) — N/A No listing

Power Conditioning Unit Output Circuits

Wire ampacity #8 THWN — 40 amperes

Routing — from Inverter Cabinet through 3/4" conduit to kWh meters and 60 amp fuse disconnect located in mechanical room.

Point of connection 400 A disconnect

APPENDIX B:
SAMPLE LOGSHEETS

HOLMAN HOUSE PHOTOVOLTAIC SYSTEM

KWH METER READINGS

	PRESENT	PREVIOUS	NET THIS PERIOD	KWH/DAY
PV SYSTEM OUTPUT				
UTILITY OUTPUT				
BUILDING INPUT				

AC CURRENT

LINE PHASE	AC MV READING	ACTUAL AC CURRENT (0.3A/MV)
1		
2		
3		

AC VOLTAGE

LINE PHASE	AC V READING	ACTUAL AC VOLTAGE (IV/IV)
1		
2		
3		

Integrated DC Current   Count from meter X .366 = Array Output (KWH)

Integrated Solar Insolation   Count from meter X 3.91 = Solar Insolation (KWH)

SOLAR INSOLATION LEVEL ____________

COLLECTOR AMBIENT TEMPERATURE ____________

VOLTMETER/TECHNICIAN DATA

VOLTMETER MFR/MODEL ____________ S/N: ____________

SHOP/ORGANIZATION ASSIGNED TO ____________ ID NO. ____________

TECHNICIAN NAME ____________ ORGANIZATION ____________ PH/EXT ____________

SIGNATURE ____________ DATE ____________ TIME ____________

NOTES:

HOLMAN HOUSE PHOTOVOLTAIC SYSTEM

SOLAR CELL ARRAY CURRENTS

ARRAY NUMBER	DC MV READING	ACTUAL DC CURRENT (0.1A/MV)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
TOTAL		

VOLTMETER/TECHNICIAN DATA

VOLTMETER MFR/MODEL ______________________ S/N: ______________________

SHOP/ORGANIZATION ASSIGNED TO ______________________ ID NO. ______________________

TECHNICIAN NAME ______________________ ORGANIZATION ______________________ PH/EXT ______________

SIGNATURE ______________________ DATE ______________________ TIME ______________

NOTES:

USA-CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWM-R
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-EC
ATTN: DAEN-ECC
ATTN: DAEN-ECE
ATTN: DAEN-ECR
ATTN: DAEN-RD
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-RM
ATTN: DAEN-ZCE
ATTN: DAEN-ZCF
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM
ATTN: DAEN-ZCZ

FESA, ATTN: Library 22060
ATTN: DET III 79906

US Army Engineer Districts
ATTN: Library (41)

US Army Engineer Divisions
ATTN: Library (14)

US Army Europe
AEAEN-ODCS/Engr 09403
ISAE 09081
V Corps
ATTN: DEH (11)
VII Corps
ATTN: DEH (15)
21st Support Command
ATTN: DEH (12)
USA Berlin
ATTN: DEH (11)
USASETAF
ATTN: DEH (10)
Allied Command Europe (ACE)
ATTN: DEH (3)

8th USA, Korea (19)

ROK/US Combined Forces Command 96301
ATTN: EUSA-HHC-CFC/Engr

USA Japan (USARJ)
ATTN: AJEN-DEH 96343
ATTN: DEH-Honshu 96343
ATTN: DEH-Okinawa 96331

416th Engineer Command 60623
ATTN: Facilities Engineer

US Military Academy 10966
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Science
ATTN: DSCPER/MAEN-A

AMMRC, ATTN DRXMR-WE 02172

USA ARRCOM 61299
ATTN: DRCIS-RI-I
ATTN: DRSAR-IS

AMC - Dir., Inst., & Servc
ATTN: DEH (23)

DLA ATTN: DLA-WI 22314

DNA ATTN: NADS 20305

FORSCOM
FORSCOM Engr, ATTN: AFEN-DEH
ATTN: DEH (23)

HSC
ATTN: HSLO-F 78234
ATTN: Facilities Engineer
Fitzsimons AMC 80240
Walter Reed AMC 20012

INSCOM - Ch, Instl. Div
ATTN: Facilities Engineer (3)

MDW, ATTN: DEH (3)

MTMC
ATTN: MTMC-SA 20315
ATTN: Facilities Engineer (3)

NARADCOM, ATTN: DRDNA-F 01760

TARCOM, Fac. Div. 48090

TRADOC
HQ, TRADOC, ATTN: ATEN-DEH
ATTN: DEH (19)

TSARCOM, ATTN: STSAS-F 63120

USACC, ATTN: Facilities Engr (2)

WESTCOM
ATTN: DEH, Ft. Shafter 96858
ATTN: APEN-IM

SHAPE 09055
ATTN: Surv. Section, CCB-OPS
Infrastructure Branch, LANDA

HQ USEUCOM 09128
ATTN: ECJ 4/7-LOE

Fort Belvoir, VA 22070 (7)
ATTN: Canadian Liaison Office
ATTN: Water Resources Support Ctr
ATTN: Engr Studies Center
ATTN: Engr Topographic Lab.
ATTN: ATZA-DTE-SU
ATTN: ATZA-DTE-EM
ATTN: R&D Command

CRREL, ATTN: Library 03755

WES, ATTN: Library 39180

HQ, XVIII Airborn Corps and Fort Bragg
ATTN: AFZA-FE-EE 28307

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

Chanute AFB, IL 61868
3345 CES/DE, Stop 27

Norton AFB, CA 92409
ATTN: AFRCE-MX/DEE

NAVFAC
ATTN: Engineering Command (7)
ATTN: Division Offices (6)
ATTN: Naval Public Works Center (9)
ATTN: Naval School, Morell Library
ATTN: Naval Civil Engr Lab. (3)

NCEL ATTN: Library, Code L08A 93041

Defense Technical Info. Center 22314
ATTN: DDA (2)

Engr Societies Library, NY 10017

Natl Guard Bureau Instl. Div 20310

US Govt Printing Office 22304
Receiving Sect/Depository Copies (2)

US Army Env. Hygiene Agency
ATTN: HSHB-E 21010

National Bureau of Standards 20760

331
03/22/85

ESS Team Distribution

HQDA (DALO-TSE-F) (3) 20310

US Army Engineer Districts (39)
ATTN: Chief, Engineer Division

US Army Engineer Divisions (15)
ATTN: Chief, Engineer Division

Army-Air Force Exchange Service 75222
ATTN: Chief, Engineering Div

Alexandria, VA 22314
ATTN: DLA-W

USA ARRADCOM 07801
ATTN: DRDAR-LCM-SP

USA DARCOM
ATTN: DRCIS 22333

Fort Belvoir, VA 22950
ATTN: DRDME-G
ATTN: DRDME-EAC
ATTN: FESA-TSD

Fort Leavenworth, KS 66027
ATTN: ATZLCA-SA

Naval Civil Engineering Laboratory 93043
ATTN: Code L03AE
ATTN: Code L60

Naval Facilities Engineering Command 22332
ATTN: Code 032E
ATTN: Code 1023
ATTN: Code 11130
ATTN: Code 044

USAF
ATTN: SAFMII 20330
ATTN: 24th CSG/DEMM 34001
ATTN: 438 CES/DEMV 08641

Andrews AFB, WASH DC 20331
ATTN: AFSC-DEE

Patrick AFB, FL 32925
ATTN: XRQ

Tyndall AFB, FL 32403
ATTN: RD

Wright-Patterson AFB, OH 45433
ATTN: POE
ATTN: PMD

Assistant Sec for Conservation & Solar Energy 20314
Assistant Sec for Resource Applications 20314
DCNO (Logistics) 20301
Director, Bldg Technology & Safety Div 20410
Director, Center for Building Technology 20234
Energy Research and Development Foundation 30037
ODAS (EE&S) 20301
ODAS (I&H) 20301
GSA 20405
Public Building Service 20405

Department of Energy 30037
Oak Ridge, TN 37830

END

FILMED

1-86

DTIC